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GAMMA AND X-RAY ASTRONOMY: NEW METHODS OF SPACE RESEARCH

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GAMMA AND X-RAY ASTRONOMY:
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Astronomy is developing rapidly in our days. However, this fact in and of itself is by no means a distinctive feature of the mid twentieth century. As a matter of fact, the rapid progress of astronomy traces from that memorable night of 7 January 1610 when Galileo first aimed his telescope into the sky.

Galileo made his telescopes with his own hands and his observations were initiated with an instrument which afforded only thirty-fold magnification. To render the greatness of Galileo's astronomical research its due, suffice it to recall that he discovered the four brightest satellites of Jupiter, the phases of Venus, mountains on the Moon and spots on the Sun. Astronomy's subsequent development can be characterized by a whole series of achievements, but we limit ourselves to pointing out that the advance of astronomy during almost 350 years (from Galileo's time up to the middle of our century) can be "measured" just by the diameter of telescopes. The diameter of Galileo's best instruments was not much more than five centimeters and their length equaled about a meter. The largest present-day telescope, put into operation in 1948, has a mirror five meters in diameter. Thus the angular resolution and illuminating power of telescopes have increased about 100 and 10,000 times respectively.

But one thing has remained unchanged in astronomy from long ago when observations were made by the naked eye alone: until recently all observations were made solely through the "optical window of transmittance" in the atmosphere. As is known, the atmosphere permits the passage of electromagnetic waves with a length greater than $\sim 3{,}000\ \text{Å} = 0.3\ \mu$ and less than several decades of microns. The human eye is insensitive except to an even narrower region of the spectrum, viz. from 0.4 to $0.75 \div 0.8\ \mu$. Consequently most observations were conducted in visible light, and the investigations -- as yet possible from the Earth's surface -- in the adjacent ultraviolet and infrared regions played a secondary part.

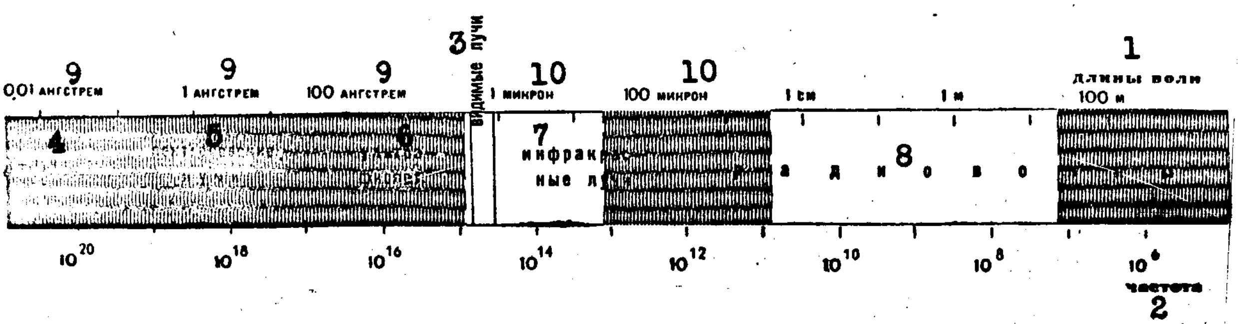

Figure 1. Scale of electromagnetic waves

Keys:

1. Wavelengths
2. Frequency
3. Visible rays
4. Rays
5. X-rays
6. Ultraviolet rays
7. Infrared rays
8. Radiowaves
9. Ångström
10. micron(s)

However, electromagnetic waves of all bands, ranging in length from hundreds of meters to infinitesimal parts of an Ångström (Figure 1), appear in the Universe and convey information. It is therefore obvious, even without special proofs, that if the Universe is observed solely through the optical window of transmittance, the resultant picture is an exceedingly poor one.

It is the appearance and ever-wider employment of non-optical methods of investigation which constitute the characteristic and most important feature in the development of astronomy at the present time (in practice, since 1945-1948). In this connection the greatest importance has come to attach to the radio method consisting in the reception of cosmic radio waves. This constitutes nowadays the task of an entire large brach of astronomy -- radio astronomy.

There exists in the atmosphere, apart from the optical window of transmittance, a "radio window." The waves corresponding to this window range in length from several millimeters to decades of meters (the Earth's atmosphere is opaque or, at any rate, not always transparent for longer waves). In less than twenty years radio astronomy has developed tremendously and is now itself already divided into a number of specialities: metagalactic and galactic radio astronomy; solar radio astronomy; seleno-planetary and radar radio astronomy. Many articles have already been written about the progress attained in each of these fields.

Electromagnetic waves whose length is outside the range of the above-indicated windows of transmittance do not reach the Earth's surface. Reaching the Earth, apart from light waves and radio waves, are only meteorites, neutrinos and gravitational waves. Meteorites have already long been studied and the information which they give about space is still far from exhausted owing to the continuing improvement in the methods of radiochemistry. Mention has frequently been made in recent time of a nascent neutrino astronomy [See Note]. The most tangible thing in this regard is the detection of solar neutrinos, which will make it possible to obtain data as to nuclear reactions taking place in the depths of the Sun. As for the reception of cosmic gravitational waves, not only has this not as yet been accomplished, but at present concrete ways of solving this task are not as yet even foreseeable in the near future.

[Note]: See Priroda (Nature), 1960, No. 8, p. 99.

With the launching of satellites and space rockets it became possible not only to make investigations by "direct methods," so to speak (as an example we may take the measurement, accomplished onboard rockets, of electron concentration in the interplanetary environment), but also to develop "satellite" and rocket astronomy. The apparatus installed onboard satellites and rockets can record radio waves lying outside the radio window of transmittance (i. e. waves less than a few millimeters and more than tens and hundreds of meters in length), far-infrared radiation (wavelength from ten microns to radio-frequency region) and all electromagnetic waves less than 0.3 μ in length, i. e. ultraviolet rays, X-rays and gamma rays. Lastly, satellites and rockets record primary cosmic rays -- in the main, protons and nuclei of different elements with energy exceeding hundreds of millions of electronvolts. In primary cosmic rays electrons and positrons are also present. Cosmic rays also convey valuable astronomical information [See Note].

[Note]: See, for example, Priroda (Nature), 1958, No. 8, pp 3-13.

Thus one can actually assert that optical astronomy has lost its quasi-monopoly position and new windows opening into the Universe have been discovered.

After this somewhat drawn-out but -- we hope -- useful introduction, let us dwell in greater detail on two interrelated astronomical specializations -- gamma astronomy and X-ray astronomy [See Note].

[Note]: A fuller exposition of the question of gamma and X-ray astronomy is contained in the authors' article in UFN [Uspekhi fizicheskikh nauk; Progress in the Physical Sciences], Vol. 84, 1964, No. 2, p. 201.

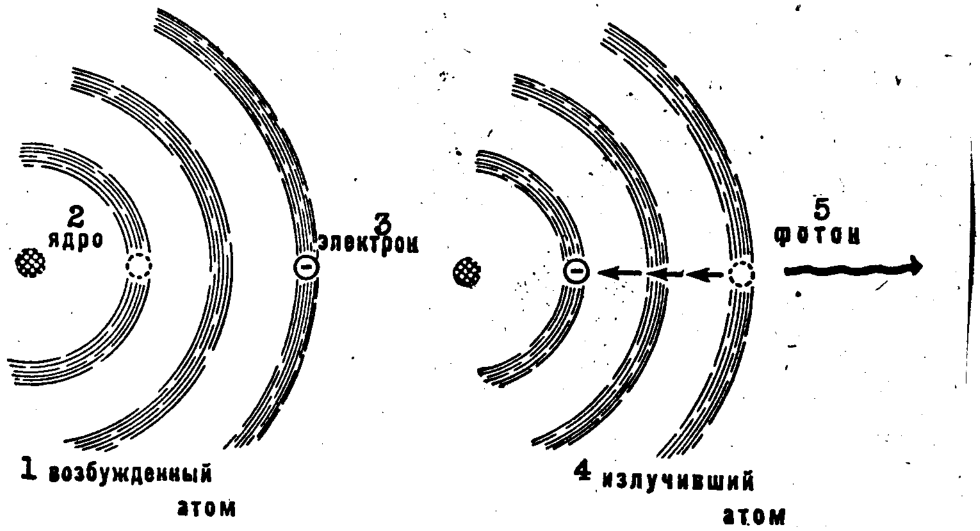

Figure 2. Irradiation during electron transfer

Keys:

1. Excited atom
2. Nucleus
3. Electron
4. Emitting atom
5. Photon

Gamma Astronomy

As is known, there is no sharp boundary between gamma (γ) rays and roentgen rays. Therefore as gamma rays we shall arbitrarily designate electromagnetic radiation whose corresponding quanta (photons) have energy [See Note] greater than 0.1 Mev = 100,000 ev or wavelength λ less than 0.1 Å. The significant difference between gamma and roentgen rays is that they usually have a different origin. Thus, roentgen rays are emitted by fairly heavy atoms during electron transition between energy levels corresponding to deep electron shells (Figure 2). In addition, X-radiation originates during the braking of fast, but as yet not relativistic, electrons (Figure 3). In contrast, gamma rays are emitted as the result of other processes which we shall now enumerate.

[Note]: Photon energy $E_{ph} = h\nu$, where $h = 6.63 \cdot 10^{-27}$ erg/sec is Planck's constant and $\nu = c/\lambda$ is radiation frequency ($c = 3 \cdot 10^{-10}$ cm/sec, and λ is wavelength in cm). Let us recall also that 1 ev equals $1.6 \cdot 10^{-12}$ erg and 1 cm $= 10^8$ Å. Therefore radiation wavelength $\lambda = 12{,}400/E_{ph}$ where λ is measured in ångströms, and photon energy E_{ph} in electronvolts.

1. In some transitions between levels gamma rays with energy up to approximately Mev originate in atomic nuclei (Figure 4).

2. Gamma rays are formed during the annihilation of an electron-positron pair (Figure 5). In this case, if the electron and positron have a low velocity and are annihilated in vacuo, usually only two gamma photons appear, the energy of each of them being $mc^2 = 0.51$ Mev, where $m = 9.1 \cdot 10^{-28}$ g is the mass of the electron.

3. They appear also during the braking of electrons whose velocity approaches the speed of light, for example as a result of their collision with protons or quiescent electrons. Originating in this case is electromagnetic radiation for which the corresponding photons have energy $E_\gamma \leqslant E$ (See Figure 3). Thus, on the basis of the boundary which we have

assumed between gamma rays and X-rays, stopping gamma rays are formed by electrons with energy E greater than 0.1 Mev.

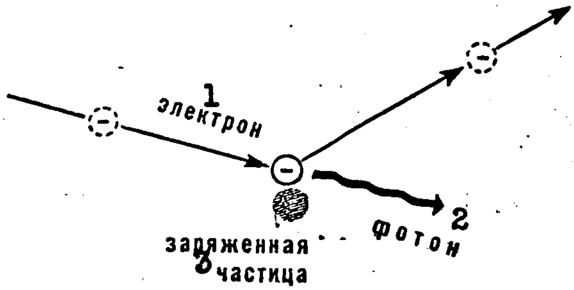

Figure 3. Bremsstrahlung during collision of electron with nucleus

Keys:

1. electron
2. photon
3. charged particle

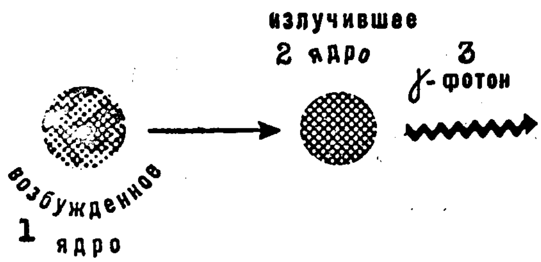

Figure 4. Radiation during intranuclear excitations

Keys:

1. Excited nucleus
2. Emitting nucleus
3. Gamma photon

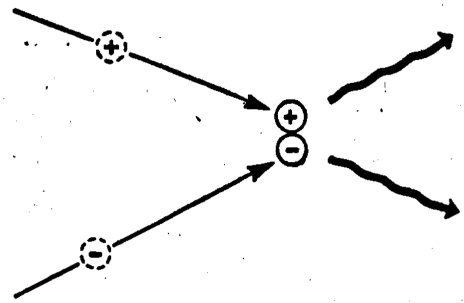

Figure 5. Annihilation of electron and positron

4. Electrons with energy great enough generate gamma rays also as a result of scattering by optical (light) photons (the so-called Compton effect) [See Note].

[Note]: The scattering of gamma quanta by quiescent or slowly-moving electrons is usually called the Compton effect. In this connection, the scattering of electrons with high energy by optical photons (the average energy of such photons for solar radiation equals approximately 1 ev) is sometimes called the reverse Compton effect. But, practically speaking, we are dealing in both cases with the identical phenomenon and there is no need here to use two designations.

In this latter process rapidly-moving electrons on colliding with light photons impart to the latter part of their energy (Figure 6). As a result the energy of the scattered photons proves to be on the average $(E/mc^2)^2$ times greater than their energy prior to scattering. Thus, light photons with energy of about 1 ev, in the event of scattering by relativistic electrons with energy $E > 300\ mc^2 \cong 150$ Mev, generate gamma rays with energies $E_\gamma > 0.1$ Mev.

5. In case cosmic rays collide with the nuclei of interstellar gas, neutral and charged pi-mesons are produced. Neutral mesons decay very rapidly, generating two gamma photons (Figure 7). The energy of these photons depends on the velocity with which the π^0-meson is moving prior to decay and on the direction of escape, but in practice always exceeds 50 Mev.

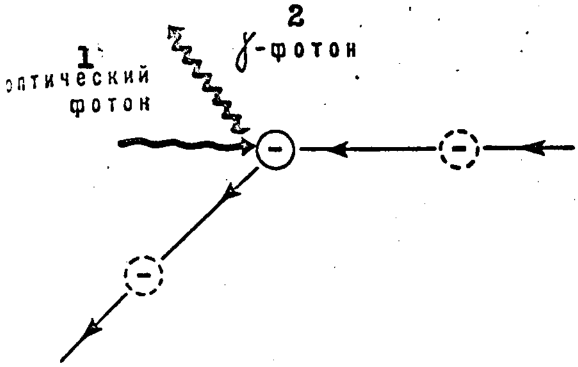

Figure 6. Electron-photon scattering (Compton effect).

Keys:

1. Optical photon 2. Gamma photon

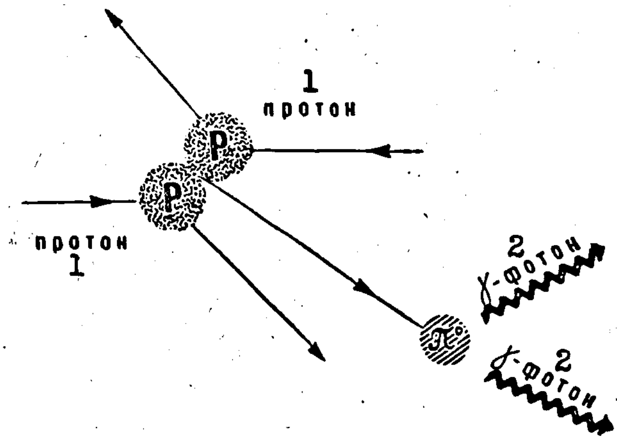

Figure 7. π^0-meson production and decay

Keys:

1. Proton 2. Gamma photon

Thus, unless we talk about nuclear and annihilation gamma rays with comparatively low energy, the principal role in the generation of gamma radiation is played by fast particles and, primarily, by cosmic rays, including their electronic component.

The intensity of the gamma rays appearing in a certain region of the Universe is obviously proportional not only to the intensity of the cosmic rays generating them, but also to the concentration of gas (or light photons in the case of process 4) in this region. Some data as to the character of the distribution of interstellar gas have already been obtained by the methods of optical and radio astronomy. As for the distribution of cosmic rays in the Universe, specific data are also available on this score, especially if it is a matter of our stellar system -- the Galaxy.

In contrast to cosmic rays gamma rays propagate in the Universe rectilinearly and practically without absorption. Therefore, in principle, observing them enables one to study directly the spatial distribution of the cosmic particles that generate these rays, and one can also refine the available data regarding the density of interstellar and intergalactic gas.

Of especial interest, besides, are the opportunities opened up by gamma astronomy for studying the Metagalaxy. As yet very little is known about cosmic rays in the Metagalaxy, i. e. outside the limits of the Galaxy. But the very first results of gamma astronomy have permitted certain valuable conclusions to be drawn on this score.

The measurements, made onboard the American "Explorer XI" satellite, of the intensity of gamma rays with energy greater than 50 Mev established an upper limit for their flux from outer space equal to approximately ten photons per square meter per second.

Analysis of these data shows that the intensity of the electron component of cosmic rays in the Metagalaxy is significantly lower (at least thirty times less) than in the Galaxy. Otherwise, as a result of electron scattering by the light photons emanating from stars and galaxies (process 4), the gamma flux would have been greater than the upper limit experimentally established.

The low intensity of electron component makes it exceedingly probable that the total intensity of cosmic rays (including protons and heavier nuclei) in the Metagalaxy is also low. This conclusion can be definitively verified with further increase in the accuracy of experiments involving the observation of cosmic gamma rays and, particularly, after the determination of the rate of the above-mentioned process of π^0-meson production and decay.

Metagalactic gamma radiation arrives here uniformly from all directions. In contrast, the gamma radiation of galactic origin is already anisotropic. For example, galactic gamma rays, resulting from the decay of π^0-mesons will come mainly from the center of the Galaxy because this is the direction in which most of the interstellar gas is concentrated (Figure 8).

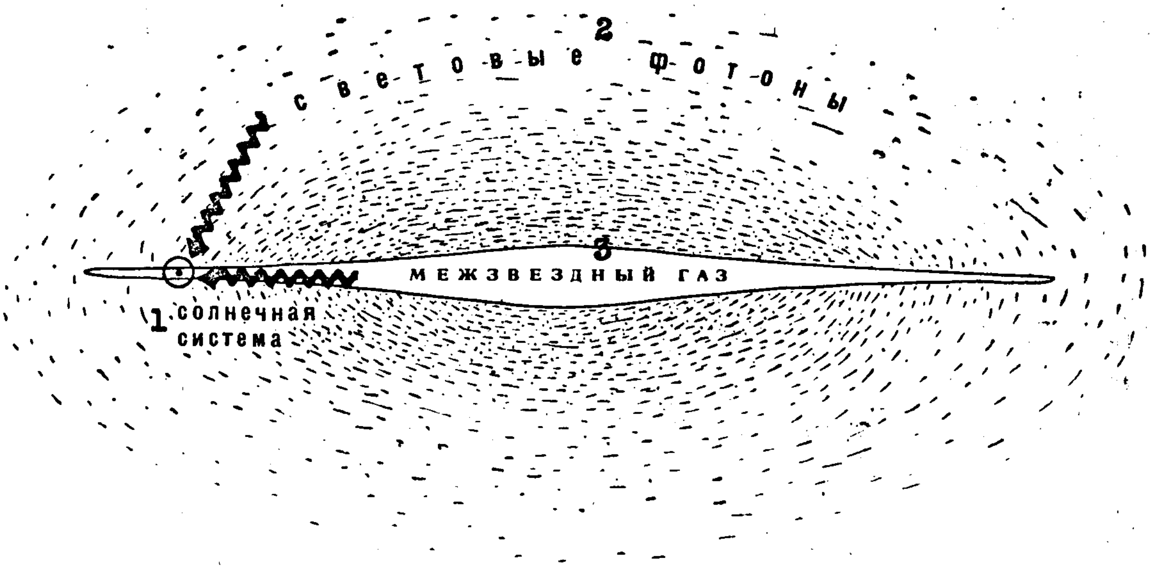

Figure 8. Distribution of matter and radiation in the Galaxy

Keys:

1. Solar System
2. Light photons
3. Interstellar gas

In addition to the general metagalactic and galactic gamma radiation generated in intergalactic and interstellar space, great interest attaches to the gamma radiation from individual so-called discrete sources. There exist in the Universe a whole series of formations (supernovae, radio galaxies, variable nuclei of galaxies and so-called hyperstars or quasi-stellars), characterized by powerful explosive processes with great release of energy. Such objects can be sources of intense gamma radiation. The reception of gamma rays from discrete sources will obviously make it possible to shed light on the nature of these sources or, at any rate, to obtain important data regarding them.

Hyperstars may be cited as an especially striking example. Not until 1963 was it established (and this discovery is with full reason regarded as the most outstanding scientific event of 1963) that in the Universe there are comparatively small, but exceptionally bright formations of a type previously unknown, and they were given the designation of hyperstars or quasi-stellar sources [See Note a]. The nature of hyperstars and the mechanism of their luminescence are still altogether obscure. One of the possibilities -- which to many seems the likeliest -- is that not only the radio emission of hyperstars but also their optical radiation is magnetic Bremsstrahlung (magnitotormoznoye izlucheniye). There is no need here to expatiate upon magnetic Bremsstrahlung or, as it is more frequently called, synchrotron radiation. Suffice it to recall that this radiation originates during the movement of charged particles (primarily electrons) in magnetic fields (Figure 9). Nonthermal cosmic radio emission is neither more nor less than magnetic Bremsstrahlung [See Note b]. But the formation of optical magnetic Bremsstrahlung in outer space as well had already been established a comparatively long time ago (such radiation is observed, for example, in the case of the Crab Nebula and galaxies NGC 4486 and M82).

[Note a]: It is the latter term which is more often employed in foreign literature. On photographic plates hyperstars are indistinguishable from stars, and their extragalactic nature was ascertained solely as a result of spectrum analyses.

[Note b]: See Priroda (Nature), 1958, No. 8, pp 3-13.

And so, let us assume that the optical radiation of hyperstars is magnetic Bremsstrahlung and let us consider, of course, just how this hypothesis is to be verified. It is not easy to do this for a number of reasons, but one of the promising ways in this matter is to use gamma astronomy. The trouble is that hyperstars are very bright but at the same time comparatively small objects (their size is apparently less than a light year whereas the diameter of our Galaxy runs to 100,00 light years. For both reasons, as is at once clear, there must be a great many optical photons in the vicinity of the emitting surface of hyperstars. Therefore scattering of relativistic electrons by photons will, with great probability, take place there. Consequently, if the optical radiation of hyperstars has a magnetic-Bremsstrahlung character, i. e. is caused by relativistic electrons, these selfsame electrons will, as a result of scattering by optical photons, yield a great many gamma rays. In other words, hyperstars may prove to be not only remarkable optical sources, but also most powerful gamma-ray sources. Unfortunately no attempt has yet been made to receive this radiation of hyperstars and, besides, this job may turn out to be especially difficult if the size of hyperstars is somewhat greater, and the concentration of photons at the surface correspondingly less, than we expect. But one thing is beyond doubt here and now: the reception of gamma radiation from discrete sources is a far from hopeless matter; quite the opposite, such reception may open up new horizons in astronomy.

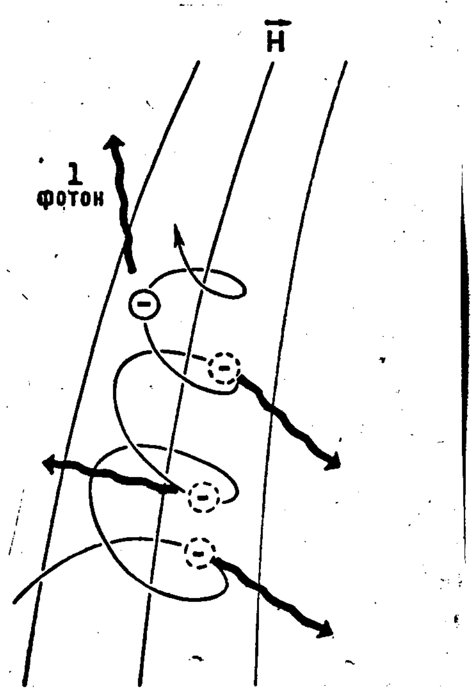

Figure 9. Magnetic Bremsstrahlung

Key: 1. photon

Lest this possibility appear excessively problematical, let us call attention to the fact that gamma radiation from a single "discrete source" not only can be received, but has in fact already been detected. We refer to the Sun. It is hardly necessary to emphasize the exceptional significance which the processes taking place on the Sun have for human life and practical activity. Especial interest is elicited in this case by solar flares which result in the formation of fluxes of hot plasma, cosmic rays, roentgen rays and powerful radio waves. It was recently ascertained that during flares gamma rays are also generated (gamma radiation with energy of about 0.5 Mev has been recorded). No doubt the gamma telescope will have a secure place amongst the instruments used to study the Sun.

Supra, we linked the progress of gamma astronomy with the development of the appropriate apparatus (it can be called a "gamma telescope") onboard satellites and rockets. Actually, the fundamental method in gamma astronomy consists in installing onboard satellites and rockets various types of counters used in nuclear physics to record gamma rays. This is not the sole method, however. Cosmic gamma radiation with high enough energy can also be registered in the Earth's atmosphere according to the secondary products which this radiation creates ("showers" of electrons, positrons and softer gamma rays).

If we take into account the progress made in the sphere of satellite- and rocket-launching, as well as the diversity of methods for recording gamma rays and the secondary products created by them, the possibility of constructing ever more highly improved gamma telescopes will be obvious.

X-Ray Astronomy

Also generated during solar flares, among the other manifestations of solar activity, are X-rays (which we have already mentioned). Solar X-rays have already been observed repeatedly and have contributed valuable data about the processes taking place in the solar atmosphere. Here, however, we are dealing with one of the aspects of a single phenomenon, studied by various methods -- by optical and radio-astronomical methods, according to variations of cosmic rays etc. Therefore it is most proper to tell about solar X-radiation in an article devoted to the physics of the Sun. However, we shall not touch upon this topic in greater detail, especially as cosmic X-radiation of non-solar provenience has been discovered now and is attracting a great deal of attention.

Experiments conducted onboard rockets in 1962 and 1963 made possible the detection of isotropic ("background") X-radiation coming from all directions almost uniformly. At the same time, in the wavelength interval between 2 and 8 Å (this corresponds to photon energy between 1.5 and 6 kev) the "X-ray telescope," consisting of photon counters, registers approximately 20 photons incident per second per square centimeter of counter surface. Detected in addition were discrete sources of X-radiation in the constellations Scorpio and Taurus (there are preliminary indications of the existence of other, weaker sources as well). The X-ray photon flux from both the above-mentioned sources amounts, respectively, to 20 and 2.5 photons per square centimeter per second (in the wavelength interval between 2 and 8 Å).

But what is the nature of cosmic X-radiation and, in particular, of the "discrete sources," which might provisionally be called "X-ray stars?" No completely definite answer has as yet been obtained to this question. X-rays -- just as gamma radiation -- may be generated by electrons as a result of their deceleration during collision with ions, or by electron scattering by optical photons. The only difference is that X-rays are produced by electrons with comparatively small energy (say, less than 1 Mev), and we know practically nothing about the number of these in the various regions of the Universe [See Note a]. This fact attests once more, though, to the value of the methods of X-ray astronomy which make it possible to obtain data about electrons with the appropriate energy. It would be entirely possible for the concretely observed isotropic X-rays to be produced in intergalactic space precisely by virtue of the scattering of these electrons by optical photons. Although this question is exceedingly interesting and we have ways to make progress (it is, primarily, a matter of making spectral observations and confirming the fact of the radiation's isotropism), the problem of discrete X-ray sources has come to be considerably more acute. This is explained by the fact that neutron stars, which have attracted attention (for the time being, in theory only) for about thirty years now, may be such sources [See Note b].

[Note a]: Usually said to be cosmic rays are charged particles of cosmic origin with energy greater than about 100 Mev. Softer particles (sometimes called subcosmic rays) cannot reach the Earth and are therefore not observed by the methods of cosmic-ray physics.

[Note b]: See Priroda (Nature), 1960, No. 11, pp 14-21.

During the burn-up of the nuclear fuel that sustains stellar luminescence stars are gradually compressed and transformed into dwarf stars consisting of dense ionized gas. However, as a star subsequently cools off -- so calculations show, its transition to the neutron state may prove to be advantageous from the energy standpoint. This means that protons combine with electrons and, emitting neutrinos, change into neutrons (process $p + e^- \rightarrow n + \nu$). In the neutron state a star has about the same density as atomic nuclei -- we are talking about an average density equal to approximately 10^{14} grams per cubic centimeter, that is about 100,000,000 tons per cubic meter. Therefore a star with the Sun's mass on transition to the neutron state has a total radius of the order of ten kilometers, whereas the radius of the solar photosphere visible to the eye comes to 700,000 kilometers (the Sun's density is about equal to the density of water, i. e. 1 g/cu meter). The amount of light emitted by a star is obviously proportional to the area of its surface, i. e. to the square of its radius. In this connection, if the Sun were to change into a neutron star (which is clearly impossible in our epoch), it would, given the same surface (photosphere) temperature, begin to emit a billion times less light. Such is the reason why it was for a long time believed impossible to observe neutron stars unless by some miracle they should prove to be situated quite close to us.

In the last two or three years it has become clear, however, that this conclusion is wrong. Actually, when a neutron star is formed, it heats up and for a certain period (say, hundreds of years) it may well be considerably hotter than the Solar photosphere, the temperature of which is about 6,000°. But the hotter a body is, the more it radiates -- in thermal equilibrium the energy of electromagnetic radiation is proportional to T^4, where T is surface temperature. Further, the hotter a body is, the greater the amount of short-wave radiation which it emits in the main, so that for the maximum in the spectrum the product of wavelength λ times temperature T remains constant (Wien's displacement law). Hence it is easy to see that a star with a temperature of 10,000,000° will, in the main, already emit X-rays [See Note]. This radiated power is so great that with existing "X-ray telescopes" one would be able to observe a neutron star thousands of light years away. So are not the X-ray sources in Scorpio and Taurus hot neutron stars?

[Note]: The maximum in the Sun's spectrum falls on wave $\lambda \cong 5{,}000$ Å. Therefore at $T = 10^7$ degrees wave

$$\lambda = \frac{5000 \cdot 6000}{10^7} = 3 \text{ Å}$$

corresponds to the maximum in the spectrum.

This question has recently attracted great attention from astronomers and physicists in many countries. At first glance, the hypothesis of the neutron nature of "X-ray stars" is seemingly easy to verify. Thus, neutron stars are so small that the X-ray source associated with them must seem to be a point source, given the highest angular resolution. Moreover, the frequency spectrum of thermal radiation is well known and one can therefore, in principle, ascertain whether it is a thermal source or not (the radiation of neutron stars has to be thermal radiation). One must not, however, forget the weak points in the newborn X-ray and gamma astronomy. Existing instruments are not yet capable of performing a spectrum analysis, and the low angular resolution is literally the "Achilles' heel" of these new branches of astronomy.

Optical astronomy provides resolution which usually does not exceed one angular second (at this angle a match box is visible at a distance of approximately ten kilometers). In radio astronomy low angular resolution was for a long time a great obstacle and not until recently was a resolution extending to fractions of an angular second obtained -- and this in exceptional cases. However, the angular resolution of the "X-ray telescopes" used does not exceed several degrees. (According to recent information it has already been possible to bring the resolving power of "X-ray telescopes" up to approximately ten angular minutes.) In this connection, direct determination of angular dimensions of X-ray sources is out of the question if these dimensions are appreciably less than several degrees. At the same time the identification of X-ray sources with visible objects is very much hampered. Thus the above-mentioned X-ray source in Taurus is in a region of the famous Crab Nebula about five angular minutes in size. Therefore it seemed quite probable that it was the Crab Nebula emitting the X-rays but there was no certitude of this fact until recently. To an even greater extent has the question as to the nature of the source remained obscure: it might prove to be a neutron star situated in the Crab Nebula, or an extended source linked with the same Nebula [See Note]. The Moon has helped to solve this vitally important problem.

[Note]: The Crab Nebula is the envelope of a supernova that burst out in 1054. The opinion is prevalent that the outburst of a supernova is associated with a star's transition (collapse) into the neutron state. Therefore the attempt to detect a neutron star in the Crab Nebula is of special interest.

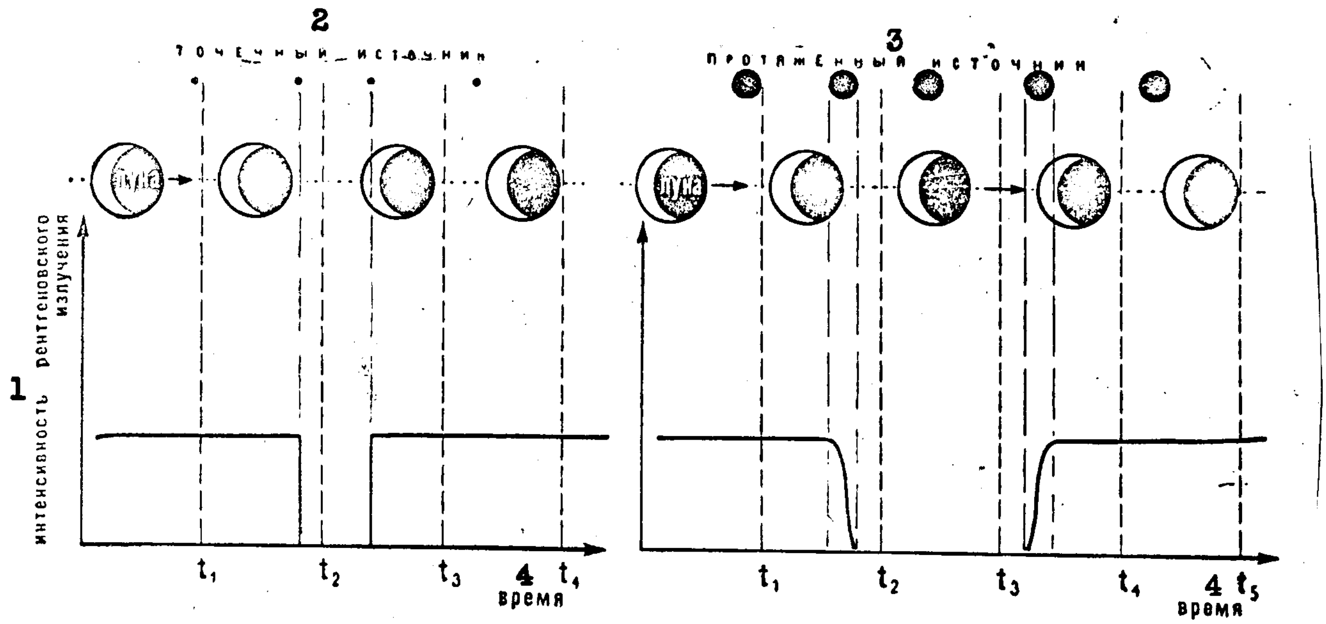

Figure 10. Variation of X-ray intensity -- as measured under terrestrial conditions -- from point (left) and extended (right) fixed sources during source's occultation by the Moon.

Keys:

1. X-ray intensity
2. Point source
3. Extended source
4. time

On 7 July 1964 the Crab Nebula was occulted by the Moon (i. e. it was shielded from a terrestrial observer by the lunar disk). During this period American physicists succeeded in dispatching a rocket with X-ray counters and it was found that precisely during the occultation of the Crab Nebula the signal from the X-ray source begins to fade. But the main thing, reception strength (the number of X-ray photons registered per time unit) diminishes in proportion with the occultation, gradually rather than sharply. This fact indicates quite definitely that the X-ray source in the Crab is not associated with a neutron star (such a star, by virtue of its negligible angular dimensions, would be occulted "all at once," i. e. reception strength would drop sharply to zero; see Figure 10) [See Note].

[Note]: Most unfortunately, the "lunar-occultation method" is exceedingly limited. In the first place, the Moon in its movement around the Earth occults only part of the firmament (we refer to the making of observations in the vicinity of the Earth); in the second place, even in those cases where occultation is possible, generally speaking it takes place very rarely. For example, the next time the Crab Nebula will be occulted will not be until 1972. By that time X-ray telescopes will probably be significantly improved and, moreover, it will be possible to make X-ray observations by means of long-range rockets, which will make it possible to bring about the lunar occultation of sources at our option (obviously for any source there is a region of space where this source is obscured by the Moon).

In all probability the X-radiation of the Crab Nebula -- just as the radio emission and the greater part of the optical radiation of this Nebula -- is of a magnetic-Bremsstrahlung nature. It will be possible to prove this assumption definitively only as a result of more detailed investigation, in particular by determining the radiation spectrum or ascertaining its polarization. But whatever the answer may be, detecting the X-radiation from the disintegrating envelope of supernovae is of prominent significance.

Nor in our view can one regard as discredited the idea as to the feasibility of observing neutron stars by their X-radiation. To be sure, as explained at present, neutron stars possibly pass over into a special superfluid state, which results in their more rapid cooling. Therefore, perhaps, a remote neutron star can be observed, even in an X-ray region, for only a few years or months after its formation. Nor do we know the frequency with which neutron stars appear in the Galaxy. From this alone it follows that there is no firm certitude that neutron stars can be observed in the near future. But surely scientific research is not conducted only when the result is known or when there is no doubt as to the success of the research. As we know, this is far from being the case, and the concrete attempt to find neutron stars is assuredly becoming one of the most alluring problems of X-ray astronomy.

* * *

Gamma astronomy and X-ray astronomy are in a nascent stage. In this field, unless we mention reception of the Sun's X-radiation, few experiments in all have been conducted. But these very first steps attest that a new and exceedingly promising method of space research has appeared. What is more, in the next few years, perhaps, gamma and X-ray astronomy will render inestimable service in behalf of the development of astronomy as a whole.